This memorandum responds to your letter of engagement dated 13 November 2015 to undertake a peer review of a memorandum dated 22 October 2015 by the UNSW Water Research Laboratory titled “Groundwater Declines at Quipolly Creek – Overview” and an associated cover letter.

1. Scope of Work

The scope of work comprises:

1. A general peer review of the memorandum.
2. Opinion of the validity of the findings.
3. Opinion of the relevance and implications of the findings of the memorandum for understanding the observed impacts to alluvial bores in the Quipolly Creek alluvium.

2. Background

The actual impacts of the Werris Creek Coal Mine operations on the groundwater source in the Quipolly Creek alluvium is the subject at issue. Mr Doug Anderson of the UNSW Water Research Laboratory was engaged by the Caroona Coal Action Group (CCAG) to provide an opinion on the reasons for recently observed declines in groundwater levels in the subject alluvium. In this report, Mr Anderson is henceforth referred to as the UNSW reviewer.

The Werris Creek Coal Mine is an open cut mine about 4 km south of Werris Creek township and about 11 km north of Quirindi in New South Wales (NSW). Its activities are confined within Mining Leases (ML) 1653, 1671 and 1672 which cover 910 hectares (ha) in area. The coal is present in the form of a small closed coal basin about 1.5 km wide (east-west) and about 3 km long (north-south). The intention is to mine the entire coal resource in this basin as defined by the outcrop extent of the basal G Seam of the Greta Coal Measures in this locality. The current project approval (PA 10_0059), issued in October 2011, permits mining to the end of 2032. Werris Creek Coal Pty Ltd (WCC) is licensed to extract or intercept groundwater through two water access licences: WAL29506 (50 ML/a) and WAL32224 (211 ML/a).

Open cut mining commenced in 2005 in the southern half of the basin, and extended into the northern half of the basin from late 2011. Earlier underground mining, which operated from 1925 to 1963, has necessitated deep dewatering prior to open cut excavation.

3. Documentation

The primary documents to be reviewed are:


Other documents relied upon for this review are:


9. Werris Creek Coal Pty Ltd (WCC), 2015b, *Werris Creek Coal Mine Water Fact Sheet*. Whitehaven Coal Pty Ltd (online).


It should be noted that important documents #6 and #7 are not cited in any of the UNSW documents.

### 4. Approach

The initial approach to this review was to read Documents #1 and #2, and to revisit Documents #5, #6 and #7 with which this reviewer was familiar nearly five years ago. More recent documents by WCC (#8 to #11) were examined to gain familiarity with activities at the coal mine over the past five years. Documents #3 and #4 (UNSW revisions) arrived after the commencement of this review.

It became clear at the outset that neither party (WWC, UNSW) had done a sufficiently thorough data analysis. Firstly, the temporal groundwater data should have been analysed through comparison of individual bore hydrographs with rainfall residual mass. Neither UNSW nor WCC has done this. Secondly, the spatial groundwater information should have been analysed through preparation of several water table contour maps at different years. Neither UNSW nor WCC has done this. Such an analysis is mandatory to resolve the causative factors for the decline in groundwater levels in time, and the spatial extent of reduced levels.

Accordingly, initial effort has focused on data analysis to clarify what has actually happened, and what has been the prevailing weather during recent time.

It should be noted at the outset that there are national guidelines for groundwater modelling and there are checklists for peer reviewing groundwater modelling components of a groundwater assessment. The UNSW reviewer makes no mention of the guidelines and has ignored the checklists in criticism of the modelling that has been undertaken. By ignoring what is best practice, the UNSW review is not systematic and not balanced, and there are elements of unreasonable expectations of best practice groundwater modelling.

The UNSW review appears not to have considered the peer review reported at Document #7, though at Document #4 it comments on the absence of "a quality environmental assessment by Whitehaven and EIS Review at Werris Creek back in 2009". The review also appears not to have considered the substantial
5. **Data Analysis**

A cause-and-effect analysis of groundwater level measurements has been undertaken. The results of the data analysis are exhibited in Figure 1 to Figure 13.

### 5.1 Spatial Trends

A composite map of groundwater level contours is presented as Figure 13 in Document #5 (RCA, 2010) and repeated as Figure 2 in Document #3 (Anderson, 2015b). It is duplicated here as **Figure 1**, with the addition of groundwater flow directions. The contours are hand-drawn interpolations of time-of-drilling water level measurements at known registered bores in 2009 (expressed as elevations in the Australian Height Datum, mAHD). Although measurements belong to different times, and measurements would have been made in different lithologies, the map is expected to be a reasonable representation of the pre-mining water table pattern over a large area from Werris Creek to Quipolly Creek, as most measurements would have pre-dated the commencement of open cut mining in 2005.

The groundwater flow directions marked on **Figure 1** show that groundwater mounds have developed beneath the hills to the east and west of the mine. They are the source areas for regional groundwater flow. It is evident that the mine is situated at a saddle on the water table surface and is not of itself a major source area for groundwater supply. The origins of the groundwater that supplies Werris Creek and its associated alluvium are marked as green flow lines. The origins of the groundwater that supplies Quipolly Creek and its associated alluvium are marked as red flow lines. The mine itself, when operational, would be expected to capture water marked as blue flow lines, with some diversion of flanking red and green flow lines.

None of the Documents referenced in Section 3 (above) shows similar contour maps since mining commenced. However, Figure 12 in Document #5 (RCA, 2010) shows subsets of contours at 2004 and 2006 based only on monitoring network bores without consideration of the source areas in the hills to the east and west of the mine.

Based primarily on water level measurements in bores that comprise the WCC groundwater monitoring network, water table contour maps have been prepared at September each year for the years 2010 (**Figure 2**), 2012 (**Figure 3**) and 2015 (**Figure 4**). To honour the known contributions of the hill sources, the monitoring network has been supplemented by four points in the western hills and two points in the eastern hills (informed by Pinneena records).

**Figure 2** (September 2010) portrays the situation after about five years of mining in the southern half of the coal basin (marked by a mauve polygon). The water table pattern at this time is very similar to the pre-mining pattern (**Figure 1**), with evidence of a saddle between the active mine area and the lower groundwater levels south of the mine lease and in the Quipolly Creek alluvium.

**Figure 3** (September 2012) shows the situation after about one year of mining in the northern half of the coal basin. There is a clear drop in the groundwater levels at the northern end of the mine, relative to the levels in 2010 (**Figure 2**). However, the water levels at the southern end of the coal basin are similar to those in 2010 and a saddle survives between the active mine area and the lower groundwater levels south of the mine lease and in the Quipolly Creek alluvium.

**Figure 4** (September 2015) shows the situation after about four years of mining in the northern half of the coal basin. There is a clear drop in the groundwater levels over the entire coal basin, most pronounced at the northern end of the mine, relative to the levels in 2012 (**Figure 3**). The water levels at the southern end of the coal basin are lower than those in 2012 and the water levels associated with the private irrigation bores are also lower than in 2012. However, a saddle survives between the active mine area and the lower groundwater levels south of the mine lease and in the Quipolly Creek alluvium.

It is evident from **Figures 2 to 4** that the reductions in groundwater levels at the mine and at the southern irrigation bores are due to different causes. Otherwise, the observed saddle on the water table surface would not be maintained. On the northern side of the saddle, groundwater flows to the north. On the southern side of the saddle, groundwater flows to the south. There is no reversal of flow from the Quipolly Creek alluvium...
towards the mine (as claimed in Document #3). The primary sources of groundwater to the Quipolly Creek alluvium remain the groundwater mounds to the east and west of the mining leases.

The status of the groundwater system at September 2015 can be visualised also by means of the depth to water map in **Figure 5**. Along Quipolly Creek, the depths are typically 5 to 15 metres (m). The more substantial depths (15-60 m) over the coal basin are indicative of localised mining effects, concentrated over the northern half of the basin. The separation of the 15 m contour between the southern end of the mining leases and Quipolly Creek is further evidence of independent causes for the lowering of water levels in the two areas.

The reduction in groundwater levels over the five-year period from September 2010 to September 2015 is shown in **Figure 6**. A maximum drawdown of about 15 m is observed at the northern end of the coal basin at two off-site monitoring bores, probably due primarily to mining near those bores. At the southern end of the mining leases, the drawdown is about 4 m. The drawdown at the private bores along Quipolly Creek ranges from 1 to 5 m. If mining were responsible for the observed drawdowns at the private bores, the radial pattern of contour lines would extend to Quipolly Creek. Clearly, it does not. There is a definite separation of the drawdown pattern between the two areas.

### 5.2 Temporal Trends

The lowering of groundwater levels can be due either to reduced recharge (supply) or increased discharge (demand). The mechanisms for recharge are rainfall infiltration and lateral replenishment along groundwater flow paths. Known mechanisms for discharge in this area are mine inflow and private abstraction (for irrigation or stock and domestic use).

To inform whether or not there is a weather component to the reduction in groundwater levels, the rainfall history must be examined. This information is best provided in the form of rainfall residual mass (RM), also known as cumulative deviation from the mean. This procedure allows focusing on rainfall trends rather than rainfall events. It is a widely used analysis tool, but has not been used by either WWC or UNSW in the Documents cited in Section 3.

Based on wide experience across Australia, the RM curve is expected to correlate well with the shape of groundwater hydrographs where rainfall recharge is a significant contributor to the groundwater response at a monitoring site. In such situations, substantial declines in rainfall will manifest as declining groundwater levels.

The RM curves (and annual rainfall bars) for the Quirindi Post Office rainfall record are shown in **Figure 7** for the entire period of record since 1883 (**Figure 7(a)**), and for the period of mining from 2005 (**Figure 7(b)**).

The main feature of the long-period RM curve is the substantial decline from 1934 to 1947. This corresponds with the serious drought during the Great Depression and World War II. Another dry period is evident from 1895 to 1903 - the Federation Drought. Progressively wetter conditions are illustrated by the gradually rising RM curve from the 1950s to the 1990s, peppered with occasional dry periods. The shorter-period RM curve (**Figure 7(b)**) shows clearly that a significant dry period occurred from early 2013 to the present day (2015). Another dry period occurred from late 2005 to early 2007. From 2007 to 2012, rainfall conditions were close to normal, with fluctuating episodes of wetter and drier conditions.

Groundwater level measurements have been made at bores in the WWC monitoring network since early 2004. The recorded hydrographs, in terms of groundwater elevation (mAHD), are compared with the RM curve to indicate whether or not the groundwater responses are in sympathy with rainfall trends. Major departures from correlation would be indicative of non-rainfall causes.

The hydrographs are grouped according to distance from the edge of the coal basin:

- Within 1 kilometre (km) of the mine: **Figure 8**.
- Within 1-2 km of the mine: **Figure 9**.
- Within 2-3 km of the mine: **Figure 10** and **Figure 11**.
- Within 3-4 km of the mine: **Figure 12**.
- Within 4-5 km of the mine: **Figure 13**.
If mining effects are occurring, they would be expected to show on Figure 8 more so than in the other figures, given closer proximity to mining. From Figure 8, sites that appear to be affected by mining are: P1 (to the south-west), P2 (to the south), MW1 (to the north-east) and MW27 (to the north-west). All four sites are within 400 m of mining. The effect at P1 is very strong, but at the other three sites the effect is mild. There might be some contribution from mining at MW2 (to the east). At the remaining sites within 1 km of mining, there is a strong correlation with rainfall trend. The declining groundwater levels since 2013, at those sites, can be explained by the strong decline in rainfall residual mass.

At all sites within 1-2 km of the mine (Figure 9) there is good correlation with rainfall trend with no evidence of a mining effect. An exception is MW10 (to the north-west) which has maintained its groundwater level through the recent drought; it is certainly not mining-affected.

In Figure 10 and Figure 11, all sites within 2-3 km of the mine show strong correlation with rainfall trend. The declining groundwater levels since 2013, at those sites, can be explained by the strong decline in rainfall residual mass. Part of the decline can be attributed to groundwater abstraction from the Quipolly Creek alluvium for the southern bores. There is no evidence of a mining effect.

Within 3-4 km of the mine (Figure 12) nearly all bores are in Quipolly Creek alluvium with a few in the underlying basalt. The up-gradient bores (MW8, MW19a, MW13b) have the most drawdown since 2012 but their hydrographs correlate strongly with the rainfall trend. This suggests that the primary reasons for the decline in groundwater levels are the recent drought and ongoing local groundwater abstraction, coupled with poorer storage properties in basalt than alluvium. The down-gradient bores show a mild correlation with residual mass variations, but on the whole their groundwater levels have been sustained throughout the recent drought with only minor drawdown. As all bores are close to Quipolly Creek, it is likely that the groundwater at these bores is replenished from the creek or from lateral flow sourced from the hills to the north-west. Document #10 cites evidence of springs in this locality.

The three bores exhibited in Figure 13, being 4-5 km from the mine, have sustained groundwater levels unaffected by rainfall trend or mining. One bore is on Werris Creek and the other two are on Quipolly Creek. Their groundwaters are likely to be sustained by the adjacent creeks.

6. Review of UNSW Opinions

The opinions of the UNSW Research Laboratory, as voiced by Mr Anderson and Mr Smith in Documents #1 to #4 are examined in this section. However, the views might not be those of UNSW per se as there is a Disclaimer at the end of Document #3 that points out that the memorandum does not constitute a Technical Report that meets the conditions of the Quality Management System of the Water Research Laboratory, and it has not been internally reviewed or independently verified by other UNSW staff.

The major sections in the main Document #3 are:

- Update 2nd November 2015
- Background
- Assumptions by Whitehaven Coal Company
- Independent Hydrogeological Review and Analysis
- Summary of Pre-Mine Baseline Conditions
- Expected Groundwater Impacts from Werris Creek Coal Mining Operations
- Observations of Groundwater Impacts
- Hydrographs
- Changes in Hydraulic Gradients
- One Dimensional Groundwater Analysis
- Assessment of Groundwater Impacts by Whitehaven Coal Company
- Issues with the Assessment of Groundwater Impacts by Whitehaven Coal Company
- Re-Analysis of Groundwater Impacts
- Review of Legislative Requirements
- Conclusions
- Recommendations
- Disclaimer
- Acknowledgement
6.1 Hydrographic Analysis

Document #3: Figure 3. This figure is poorly laid out and consequently it is very difficult for a reader to make an informed interpretation of the exhibited data. The data analysis fails to take into account rainfall trends, as revealed by the residual mass procedure in Section 5.2 above, ignores spatial trends as revealed in Section 5.1 above, and postulates the causes for apparent hydraulic gradients without any consideration of distance from the mining operations.

Many of the claims are without evidentiary foundation, for example:

- That MW8 has an instantaneous response to mining about 4 km away during 2005-2007 when mining commenced; as Figure 12(b) shows that the hydrograph mirrors the RM curve precisely, rainfall decline is the proper and most reasonable explanation, other than contributory local abstraction.
- That “Groundwater at MW28a appears to be flowing NNW towards MW6 and possibly into the mine” at June 2006. In this particular month the head at MW28a was 0.5 m higher than at MW6. However, this does not predicate the direction of groundwater flow. Figure 3 shows that flow is to the west (or a little south of west), definitely not NNW towards the mine as claimed. On the basis of this false claim, a theory is put forward to give the erroneous impression that groundwater is being drained from the Quipolly Creek alluvium to the mine.
- That the “groundwater levels at MW28a start falling rapidly” despite high annual rainfall at March 2013. The RM curve in Figure 7(b) shows that the rainfall trend is downwards from this date, and that is the logical reason for the observed decline at MW28a.
- That “there is still a hydraulic gradient towards the mining pit from MW28a to MW6” at March 2014. In fact, the head at MW6 at that time was 1.1 m higher than at MW28a, so there is no gradient towards the mine as claimed. The hypothesis of a “groundwater discharge or capture zone in the SE corner of the former mine workings” is without substance in fact and in logic.

The claim of a negative hydraulic gradient [Document #3, p11] in September 2012 is incorrect, as can be visualised on Figure 3. There is no evidence for groundwater flow reversal from the Quipolly Creek alluvium to the mine. On the contrary, there is strong evidence for flow in the opposite direction, towards Quipolly Creek. Subsequent volumetric flow calculations [Document #3, p11] do not bear scrutiny. These calculations suggest that 50-500 ML/year is prevented from flowing south to the Quipolly Creek alluvium. In fact, the volume cannot exceed mine inflow, reported as 62 ML/year in Document #8 for 2014-2015, and most of this would come from storage on the northern side of the saddle identified in Figures 2-4. Comparison of the so-called captured volume with 1000 ML/year is spurious and misleading because this quantity is total mine water use and not mine inflow from groundwater.

6.2 Landholder Use

Document #3 [Table 2] provides a useful estimate of likely groundwater use by landholders. The assessment gives a total of about 209 ML/year, which is about three times the reported mine inflow in Document #8 for 2014-2015.

One would expect that, after allowing for differing lithology permeabilities, the drawdown pattern (or cone of depression) would be similar in strength and extent for the mine and for the Quipolly Creek alluvium where groundwater abstraction is concentrated. A comparison of the separate patterns is provided in Figures 2-4 for 2010, 2012 and 2015. At September 2010, there is a pronounced pattern of lower groundwater levels in the alluvium, but very little effect seen at the mine. As mining progresses, the pattern over the northern part of the mine develops but the pattern in the alluvium remains similar to earlier years. These responses are a clear indication of separate stresses on the groundwater system.

Document #3 [p8] argues that “the construction of any open cut pit within the recharge zone of Quipolly Creek must reduce groundwater flow towards Quipolly Creek”. From Figure 1 it is clear that the northern half of the coal basin, where mining has been focussed from late 2011, is not within the recharge zone of Quipolly Creek.
6.3 Baseline Conditions

Document #3 is critical of the monitoring and field investigations undertaken for the project.

The criticism of monitoring is considered unfair, as the monitoring network has been in place since 2004, with most monitoring sites commencing in 2005. A decade of data is much better than commonly found at mining sites. A suitable standard for baseline monitoring is a period of two years as a minimum as defined in the Aquifer Interference Policy, to which the UNSW reviewer makes no reference. WWC has complied with this requirement.

The criticism of field investigations also is considered unfair. WWC has conducted field tests at 13 sites, as reported in Document #4. The sites appear to be distributed sensibly.

The amount of effort required in a groundwater assessment should be tempered by the perceived risks. This is in line with the tenor of the Aquifer Interference Policy, which states:

"A risk management approach to assessing the potential impacts of aquifer interference activities will be adopted, where the level of detail required to be provided by the proponent is proportional to a combination of the likelihood of impacts occurring on water sources, users and dependent ecosystems and the potential consequences of these impacts."

6.3 Criticism of Regulators

Document #3 offers opinions on Issues with the Assessment of Groundwater Impacts by Whitehaven Coal Company [p14] and a Review of Legislative Requirements [p15-16]. The matters raised are best addressed by DPI Water. However, some comments are offered here.

At Document #3 [p14], the UNSW reviewer is essentially criticising DPI Water for not requiring WWC to licence rainfall intercepted by the mine. It "should be reported as an incidental groundwater take on WWC's groundwater licence in addition to the direct take". As rainfall is not a State right, DPI Water has no authority to require licensing of such water.

Also at Document #3 [p14], the UNSW reviewer is critical of "non-unique model calibrations". This gives the false impression to a lay reader that unique calibrations are the norm, whereas every groundwater modeller should know that non-uniqueness is an inescapable feature of groundwater modelling. The UNSW reviewer also seems to expect reporting of evaporation from water storages when they are not standard elements of a groundwater model. In the same paragraph, he misleads the reader by suggesting (erroneously) that "the groundwater model is not based on field measurement of aquifer properties between the mine and landholder bores", and that "parameters that are adopted for modelling impacts appear inconsistent with available aquifer test data and typical literature values" - the latter always being of dubious value in the experience of this reviewer.

6.3 Criticism of Groundwater Modelling

Throughout Document #3 there are numerous slights on the groundwater modelling that has been undertaken. The criticisms do not follow a structured approach as advocated in national groundwater modelling guidelines. A structured peer review [Document #7] was conducted at the time of application for the northern extension of the Werris Creek Coal Mine, but the UNSW reviewer makes no reference to this, nor to Document #6 where responses were made to points raised in the original peer view.

A major criticism of the groundwater modelling is that the process of mechanical unloading was not considered. Firstly, it is recognised that this process would occur in reality. Secondly, it is noted that the national guidelines on groundwater modelling do not mention the concept, and therefore the guidelines have no expectation that this process should be modelled. The reason is that inclusion of this process is beyond the state of the art for groundwater modelling at the present time, and for the foreseeable future. Its inclusion would require coupled flow-stress modelling, in other words a fusion of geotechnical and hydrogeological mathematics. Despite having reviewed about 300 models in the past 15 years, this reviewer has never seen a groundwater model that includes mechanical unloading. Such as expectation is unreasonable.

It is true that the depressurisation directly beneath an open cut coal mine, were it to be measured, would have a substantial mechanical unloading component. However, the effect would dissipate rapidly away from
the mine footprint, as the impact on a confined aquifer can be no more than a small fraction (less than the specific yield, typically 10-30%) of the drawdown in the overlying water table. At most observation bores the effect would be negligible. The effect of ignoring the process would be that mine inflow would be overestimated due to an overestimation of vertical permeability. However, this would be conservative in terms of potential environmental impacts.

Document #4 also hints at more detailed modelling of the various permeabilities through a vertical section of basalt. The WWC model already devotes five of the seven model layers to basalt. The degree of stratigraphic detail incorporated in a model is a decision that should be pragmatic in terms of computational capability and in keeping with the risk management approach advocated in the Aquifer Interference Policy.

Document #4 also is critical of the adopted magnitudes for specific storage. This criticism was raised in the original peer review [Document #7]. Subsequently, the specific storage was reduced in the model and tested for sensitivity [Document #6].

The effort put into groundwater modelling should be commensurate with risk. This is the tenor of the Aquifer Interference Policy.

7. Conclusion

The opinion of this reviewer is that the peer review conducted by the UNSW Water Research Laboratory has reached erroneous conclusions based on inadequate data analysis and misinterpretation of cause-and-effect relationships between the acquired groundwater data and the observed effects on the groundwater system.

A groundwater assessment should be commensurate with risk. This is the tenor of the Aquifer Interference Policy, which advocates a risk management approach that takes into account likelihood and consequence. The Policy and the advocated approach are ignored in the UNSW peer review.

The UNSW reviewer mentions the Quipolly Dam operations as a possible contributor to minor reductions in alluvial water levels. This is quite possible, but the reviewer has no knowledge of the changes made to the dam crest, the timing of such changes, or changes in the operational protocols of the dam. Hence, no informed comment can be made by the reviewer on this potential cause.

In summary, the key weaknesses in the UNSW Water Research Laboratory peer review are considered to be:

- No reference to national groundwater modelling guidelines.
- Not using best practice peer review protocols.
- Not allowing for the risk management tenor of the Aquifer Interference Policy.
- Inadequate data analysis which did not take into account rainfall trends, spatial patterns or distance of impact sites from mining.
- Misinterpretation of groundwater responses temporally and spatially.
- Unsubstantiated and illogical attribution of impacts to mining.
- Inadequate consideration of the recent drought as a plausible explanation for observed impacts.
- Unreasonable expectations of groundwater modelling without regard to the state of the art or the requirements of the Aquifer Interference Policy.

This reviewer finds no case for the conclusion of the UNSW reviewer that "it is likely that coal mining operations at WCC's Werris Creek Mine are contributing to the impacts currently being observed at landholder bores".
Figure 1. Pre-Mining Water Table Contours and Groundwater Flow Directions [modified from RCA, 2010]
Figure 2. Measured and interpolated groundwater level at September 2010
Figure 3. Measured and interpolated groundwater level at September 2012
Figure 4. Measured and interpolated groundwater level at September 2015
Figure 5. Measured and interpolated depth to water at September 2015
Figure 6. Measured and interpolated drawdown from September 2010 to September 2015
Figure 7. Rainfall and rainfall residual mass at Quirindi Post Office
Figure 8. Observed bore hydrographs within 1 km of mine
Figure 9. Observed bore hydrographs within 1-2 km of mine
Figure 10. Observed bore hydrographs within 2-3 km of mine
Figure 11. Observed bore hydrographs within 2-3 km of mine (on eastern ridge)
Figure 12. Observed bore hydrographs within 3-4 km of mine (along Quipolly Creek)
Figure 13. Observed bore hydrographs within 4-5 km of mine (along Quipolly Creek and Werris Creek)